facilitate reconfigurability of the transmission lines and implementation on for example a chip.

[0024] In some example embodiments, there may be provided a bandpass filter including the phase shifter. For example, the phase shifter may provide a tunable bandpass filter, which may be used in a variety of frameworks including bands associated with Long Term Evolution (LTE), although other radio technologies may include the disclosed bandpass filter including phase shifter.

[0025] In some example embodiments, the disclosed transmission line structure may, in some example embodiments, comprise a tunable inductor.

[0026] In some example embodiments, there may be provided a phase shifter comprising transmission lines coupled to switches to enable reconfiguration of the transmission lines and corresponding selections of characteristic impedance, Zo, and of phase shift, Phi. For example, the phase shifter disclosed herein may be coarsely adjusted in both phase shift and characteristic impedance levels, and this adjustment may be performed independently to phase shift and to impedance levels by reconfiguring the periodic transmission lines via the switches. Moreover, the structure of the phase shifter comprising transmission lines and switches may, in some example embodiments, provide a periodic layout structure, which may facilitate reconfigurability of the transmission lines and implementation on for example a chip.

[0027] In some example embodiments, there may be provided a switched-line phase shifter having a tunable capacitor bank network provided by a combination of a network of broadband transmission lines that may maintain characteristic impedance over a wider bandwidth. The broadband transmission line structure may be coarsely adjusted in both phase shift and characteristic impedance levels independently. This coarse adjustment may be provided by re-configuring the periodic transmission-line structure. Consequently, an increased amount of combinations of, for example, Zo and Phi may be provided, without resorting to lossier higher-order multi-throw switches. Moreover, tunable capacitors may be included for fine-tuning. Furthermore, a tunable inductor may also be provided. This tunable inductor may enable a tunable filter.

[0028] FIG. **1** depicts an example of a block diagram of a model of the phase shifter **100**, in accordance with some example embodiments. The phase shifter may include a broadband tunable quarter-wavelength (λ/4) resonator transmission line **102**A-B intersected by a network of one or more tunable shunt capacitors **104**, which may be centered at the transmission line **102**A-B. The phase shifter **100** may form a filter-tee network, which represents a tunable inductor.

[0029] FIG. **2** plots simulated inductance values for the tunable phase shifter of FIG. **1**. FIG. **2** depicts an array of inductance values for a variety of transmission line characteristic impedance values at a shunt capacitance, C_L **104**, of for example, 0.5 picofarads (pF), although other capacitance values may be used as well. When this is the case, the inductance values are plotted using a system impedance, Zc (for example, about 50Ω), equal to about the characteristic impedance, Zo, of the phase shifter **100**.

[0030] FIG. **3** depicts an example half section of tunable transmission line **300**, in accordance with some example embodiments. This half section may be used at each of the half sections **102**A-**102**B of tunable quarter-wavelength (λ/4) resonator transmission line depicted at FIG. **1**. Although FIG. **3** depicts three sections, other quantities of transmission line sections may be used as well.

[0031] In the example of FIG. **3**, the half section tunable transmission line (I=λ/8) may include an RF input **305**, a transmission line structure comprised of three sections **307**A-C, one or more switches coupling each of the sections and/or the top and bottom portions of the transmission line structure, and an RF output **320**. The electrical length of the transmission line structure may be coarsely controlled by selecting a quantity of coupled sections **307**A-C to add to the RF path between the RF input **305** to the RF output **320**. Changing the length of the RF path effectively changes the phase shift (Phi) provided by half section tunable transmission line **300**.

[0032] One or more of the sections **307**A-B may be coupled into the RF path from RF input **305** to RF output **320** via switches **309**A-C. By controlling the activation of switches **309**A-C and thus the addition of one or more transmission line sections, the electrical length of half section tunable transmission line **300** may be controlled, which corresponds to the amount of phase shift (Phi) provided by half section tunable transmission line **300**. The switches S_1-S_3 **309**A-C may also provide a coarse control of the characteristic impedance, Z_O, provided by the RF path (for example, the RF path from RF input **305** to RF output **320**) in which the RF current propagates through the transmission line. Fine control of the characteristic impedance, Z_O, may, in some example embodiments, be provided by the variable capacitors **350**A-L.

[0033] FIG. **4** depicts additional example configurations of the half section tunable transmission lines, in accordance with some example embodiments. The different configurations (a)-(c) may be provided by configuring the one or more switches, which may be placed along the axis **402**A-C. Although FIG. **4** depicts four sections, other quantities of transmission line sections may be used as well.

[0034] FIG. **4**(*a*) depicts a cross configuration of switches providing a path **405**A-L. FIG. **4**(*b*) illustrates a series configuration of switches providing a path **410**A-E. In the configuration of FIG. **4**(*b*), the series-coupled line **410**A-E provides an RF current path that does not cross the axis of symmetry. FIG. **4**(*c*) depicts a mixed-coupled structure having cross-coupled connections and series-coupled connections. In the aforementioned coupling schemes at FIG. **4**(*a*)-(*c*), the RF sections may be coupled into (or out of the path) to coarsely control the transmission line's phase shift (Phi) and characteristic impedance, Z_O. The characteristic impedance, Z_O, at FIG. **4** may be finely adjusted, in some example embodiments, by varying the capacitance values that load each cross-section (not shown in FIG. **4** but shown at FIG. **3** at **350**A-L).

[0035] FIG. **5** depicts other example implementations of the phase shifter, in accordance with some example embodiments. FIG. **5**(*a*) depicts a constant impedance phase shifter using four sections per half circuit, and FIG. **5**B depicts two sections per half-circuit. When the electrical length of the transmission line is changed while substantially maintaining the characteristic impedance, Z_O, the phase shifter may operate over a wider range of coarse frequencies. This may enable the phase shifter to be used as a tunable filter to operate over one or more RF bands.

[0036] Referring again to FIG. **5**(*a*), all eight transmission line sections **510**A-H are activated via the switches **512**A-H, when compared to FIG. **5**(*b*) where only four sections are activated (for example, coupled into the transmission line